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Discordance in National Estimates of Hypertension Among Young Adults

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Abstract

Background—In the U.S., where coronary heart disease (CHD) is the leading cause of mortality, CHD risk assessment is a priority and accurate blood pressure (BP) measurement is essential.

Methods—Hypertension estimates in the National Longitudinal Study of Adolescent Health (Add Health), Wave IV (2008)—a nationally-representative field study of 15,701 participants aged 24–32—was referenced against NHANES (2007–2008) participants of the same age. We examined discordances in hypertension, and estimated the accuracy and reliability of blood pressure in the Add Health study.

Results—Hypertension rates (BP ≥ 140/90 mm Hg) were higher in Add Health compared with NHANES (19% versus 4%), but self-reported history was similar (11% versus 9%) among adults aged 24–32. Survey weights and adjustments for differences in participant characteristics, examination time, use of anti-hypertensive medications, and consumption of food/caffeine/cigarettes before blood pressure measurement had little effect on between-study differences in hypertension estimates. Among Add Health participants interviewed and examined twice (full and abbreviated interviews), blood pressure was similar, as was blood pressure at the in-home and in-clinic exams conducted by NHANES III (1988–1994). In Add Health, there was minimal digit preference in blood pressure measurements; mean bias never exceeded 2 mm Hg; and reliability (estimated as intra-class correlation coefficients) was 0.81 and 0.68 for systolic and diastolic BPs, respectively.

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NOTE TO CADMUS: We are intentionally spelling out "BP" in some places and leaving it as "BP" in other places. Please leave this as we've expressed it.

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Conclusions—The proportion of young adults in NHANES reporting a history of hypertension was twice that with measured hypertension, whereas the reverse was found in Add Health. Between-survey differences were not explained by digit preference, low validity, or reliability of Add Health blood pressure data, or by salient differences in participant selection, measurement context, or interview content. The prevalence of hypertension among Add Health Wave IV participants suggests an unexpectedly high risk of cardiovascular disease among U.S. young adults and warrants further scrutiny.

In the United States, coronary heart disease (CHD) is the leading cause of mortality—accounting for more than half a million deaths annually.[1] Blood pressure (BP) measurement is integral to CHD risk assessment and diagnosis of hypertension, a behaviorally and pharmacologically modifiable CHD risk factor. It has been estimated that each 1 mm Hg increase in mean population systolic BP is associated with approximately 10,000 additional CHD deaths.[2]

National estimates of hypertension prevalence in the United States rely almost exclusively on the National Health and Nutrition Examination Survey (NHANES).[3,4] However, NHANES is not without limitations. For example, group-specific estimates are unavailable for racial/ethnic minorities other than Hispanics and non-Hispanic Blacks. NHANES' cross-sectional design also prohibits the study of precursors and individual trajectories in the development of hypertension. Furthermore, its assessment of hypertension rates among young adults is hindered by small sample sizes. Several factors fuel interest in the measurement of physical health during young adulthood [5]—one usually characterized by the absence of adverse health conditions.[6] A particularly important example is the sharp escalation among youth of overweight and obesity, both of which are well-known risk factors for hypertension.[7] The prevalence of overweight children has tripled in the last two decades alone.[8]

In 2008, the National Longitudinal Study of Adolescent Health (Add Health, Wave IV) expanded collection of biologic data, including in-home measurement of blood pressure among 15,701 young adults aged 24–32 years throughout all 50 states. We compared mean blood pressure and hypertension prevalence in this population with that of similarly aged participants in NHANES 2007–2008,[9] and examined putative explanations for the observed discordance between surveys.

The measurement of blood pressure in nationally representative field studies such as Add Health is distinct from (and arguably more complicated than) that in exam center-based studies, requiring measurement in more variable home environments, many more field staff, and large numbers of portable, affordable blood pressure monitors. Although the quality of blood pressure data collected in exam centers by trained technicians using clinical equipment has been described,[10,11] studies capable of supporting population-wide inferences that have examined the quality of in-home blood pressure data are scarce. We therefore examined the accuracy and reliability of blood pressure in Add Health, Wave IV, as well.

METHODS

Add Health study design

Add Health enrolled a probability sample of 20,745 U.S. adolescents in grades 7 through 12 during the 1994–1995 school year (Wave I response rate: 79%).[12] Three in-home follow-up interviews of the cohort have been completed since then: Wave II in 1996 (88% of the eligible cohort at Wave I), Wave III in 2001–2002 (77%), and Wave IV in 2008 (80%). Each wave of this study, approved by the University of North Carolina at Chapel Hill Public

Health-Nursing Institutional Review Board, complied with regulations governing human subjects research.

Detailed information on the study's cardiovascular measurements has been published elsewhere.[13] Briefly, all 15,701 Add Health participants completing the Wave IV interview were asked whether they had ever been told by a health care professional that they have hypertension (i.e. self-reported history of hypertension). Women were asked to exclude diagnoses during pregnancy. After the interview, participants rested in a seated position for five minutes, after which three measures of resting, seated blood pressure were recorded. There were 323 trained and certified field interviewers who followed a computer-assisted data collection protocol.[13] Add Health attempted to collect blood pressure on all its respondents, including those in prison and the military. Blood pressure was recorded from the right arm at 30-second intervals using a cuff matched to arm circumference (adult, 24.0–33.7 cm; large adult, 33.7–40.6 cm) and a $65 automatic oscillometric monitor with an advertised resolution and accuracy of 1 and 3 mm Hg, approved by the British Hypertension Society (BP 3MC1-PC_IB; MicroLife USA, Inc.; Dunedin, FL). After blood pressure measurement, the interviewer inventoried antihypertensive medications (beta-adrenergic blockers; calcium channel blockers; angiotensin converting enzyme inhibitors; angiotensin II receptor blockers; centrally or peripherally acting anti-adrenergics; vasodilators; thiazide diuretics; antihypertensive combinations) used by participants within the preceding four weeks by visually inspecting participant-assembled medication containers and automatically categorizing their contents in real-time using Lexicon Plus™ (Lexi-Comp®, Inc.; Hudson, OH). Following 11% of interviews, post-encounter telephone calls using a standardized script[13] were made to participants to verify, among other things, field interviewer adherence to the blood pressure protocol.

To ensure the accuracy of systolic and diastolic BPs reported to participants, the second and third measures of each were double-entered, automatically checked in real-time for discrepant entries or values exceeding the monitor-specific range of measurement (30–280 mm Hg), averaged, and then classified according to Joint National Committee (JNC) 7 guidelines.[14] All summary statistics involving Add Health data were estimated using STATA®/SE 10 (StataCorp LP, College Station, TX), with sample design variables to account for clustering and to produce nationally representative estimates.[12]

NHANES study design

The National Health and Nutrition Examination Survey (NHANES) 2007–2008[9] is a population-based, cross-sectional survey of the civilian, non-institutionalized U.S. population conducted by the U.S. Centers for Disease Control and Prevention and the National Center for Health Statistics. Participants were selected with a stratified, multistage probability sampling design. The survey included health interviews conducted in participants' homes and health measurements made in mobile examination centers during morning (8:30am), afternoon (1:30pm), and evening (5:30pm) sessions. Of the 12,943 households approached, 10,149 provided interviews (response rate = 78%) and 9762 participants were examined (response rate = 75%). Similar response rates were seen among participants 20–39 years of age.

During the in-home interviews, antihypertensive medications were inventoried in the same manner as for Add Health. Participants were asked whether they had ever been told by a health care professional that they have hypertension (i.e., self-reported history of hypertension). Blood pressure was measured on all participants 8 years of age or older by certified physician examiners using a Baumanometer calibrated mercury true gravity wall model pressure gauge. Blood pressure was taken after participants rested in a seated position for five minutes; typically three measures of blood pressure were recorded in 30-second intervals. All summary statistics were estimated using STATA®/SE 10 (StataCorp LP, College Station, TX), with sample design variables taken into account for clustering and to produce nationally representative estimates.

Cross-survey comparisons

Cross-survey comparisons were made among adults aged 24–32 years with valid blood pressure and survey weights. The analysis sample included 14,252 Add Health participants (47 aged 33–34 years were excluded) and 733 NHANES 2007–2008 participants. Mean blood pressure and prevalence of hypertension (BP ≥ 140/90 mm Hg) for Add Health participants were referenced against NHANES participants before and after weighting for unequal sampling probabilities, clustering and predicted probabilities of participant selection (propensities).[15] Propensities were conditional on age (years), race/ethnicity (non-Hispanic white; non-Hispanic black; Mexican; other Hispanic; other race/multiracial), sex, education (<high school; high school/ high school equivalency degree (GED); some college/ Associate's degree; 4-year college or more), annual household income (< $20,000; ≥ $20,000), health insurance status (insured; uninsured), body mass index (underweight; normal weight; overweight; obese class I; obese class II/III), current daily smoking (yes; no), heavy alcohol use in previous 12 months (none; < weekly; ≥ weekly), separately coded consumption of food, caffeine intake and smoking in the 30 minutes before blood pressure measurement, and time of measurement session (morning, afternoon, evening). In Add Health, heavy alcohol use was assessed via the following question: "During the past 12 months, on how many days did you drink 5 or more (among men) or 4 or more (among women) drinks in a row?" In NHANES, respondents were asked, "In the past 12 months, on how many days did you have 5 or more drinks of any alcoholic beverage."

Weighted logistic regression models were used to estimate the predicted probabilities of selection into Add Health (versus NHANES) conditional on participant characteristics. Add Health and NHANES sampling weights were then adjusted via multiplication by the inverse predicted probabilities of selection.[16] Persons in categories under-represented in Add Health versus NHANES were thereby given higher weight, and vice versa. We then recomputed mean systolic and diastolic BP in Add Health and NHANES using these adjusted weights. Finally, logistic regression models were used to estimate the odds of hypertension in Add Health versus NHANES using adjusted weights and controlling for the full set of above-mentioned covariates.

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Within-survey comparisons

To explore the effect of measurement context, we used NHANES III (1988–1994)[17] to contrast mean blood pressure measured in the home and the mobile examination center among participants aged 24–32 with valid blood pressure at both exams (n = 2949). To explore the effect of interview content, we used Add Health, Wave IV to contrast blood pressure after the full, 1.5-hour interview (Visit 1) and after the 5-minute, abbreviated interview (Visit 2) among the 100 participants examined twice in the reliability study, described below. The 1.5-hour interview contained questions regarding child maltreatment, intimate partner violence, and suicide, among other provocative topics, while the 5-minute interview did not.

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Digit preference in Add Health

This investigation also assessed validity and reliability of Add Health blood pressure measurements, beginning with digit preference. Overall and, sample-size permitting,[18] field-interviewer-specific terminal digit preference of concordant double-entries was monitored using a Pearson χ^2 test of the null hypothesis that all possible terminal digits (0,1,2,…9) were observed with equal frequency. Exact tests were implemented when the number of field-interviewer-specific participant observations was less than 50. Adjustments for multiple comparisons were made using the Bonferroni method by dividing the conventional alpha of 0.05 by (1) 6, in the overall analysis of the 3 systolic plus 3 diastolic BP measures and by (2) 6 × 323 = 1938, in the analysis of field-interviewer-specific systolic BP and diastolic BP measures. Calculation of a digit preference score (DPS) was also used to reduce Type I error otherwise inherent in identification of divergence from a uniform distribution of terminal digits at even modest sample sizes. $\mathrm{DPS}=100\times\sqrt{\chi^2/N(k-1)}$, range: 0–100; where N = number of observations per FI and k = number of terminal digits. The identification of field-interviewer-specific digit preference (DPS ≥ 20) would suggest the possibility of data fabrication.[19,20]

Validity study in Add Health

Between December 2008 and July 2009, two technicians visually inspected the 292 monitor / cuff pairs returned from the field at study closure for damage, missing parts and electronic malfunction using a standardized data collection form and protocol.[13] The technicians also reassessed accuracy of pressures measured using the adult and large-adult cuffs by applying them to rigid cylinders 28.5 and 37 cm in circumference, respectively, and connecting them in tandem to a factory-calibrated pressure meter (Netech DigiMano, Model 2000; Netech Corporation; Farmingdale, NY). Seven field monitors were excluded because no measurements could be obtained after three attempts. Because several monitors were returned with only a single cuff, the remaining 285 monitors produced only 548 monitor-cuff records of pressures over a range of 280 to 40 mm Hg in 20-unit decrements. At each of these thirteen meter pressures, accuracy was computed as the difference between the monitor and the meter pressure (bias, mm Hg) and its ratio with respect to the criterion standard (relative bias, % = 100 × bias / meter pressure).

Both measures were initially subjected to conventional Bland-Altman analyses.[21] Subsequent bias analyses relied on a three-level, random-intercept model in which i, j and k denote the bias of the ith monitor pressure (level 1) measured by the jth cuff (level 2) and kth monitor (level 3). The basic model is given by:

$$Y_{ijk}=\beta_0+\beta_1P_{ijk}+\beta_2C_{ijk}+\gamma_{1k}+\gamma_{2j(k)}+\varepsilon_{ijk},$$

where Y_{ijk} is bias (mm Hg) is β_{0-2} are fixed-effect parameter estimates, and γ_{1-2} and ε_{ijk} are random effects. In this model, β_0 is the intercept, P_{ijk} is a vector of meter pressure categories (1–13), and C_{ijk} is a vector of covariates including technician (0; 1), technician experience (mean 3.3; range 0–7 months), cuff size (adult; large adult), number of missing pressures per monitor / cuff pair (mean: 1.9; range: 0–12), and an indicator flagging monitor / cuff pair assessments in which a monitor had to be restarted to acquire otherwise missing data (56% of the time). The term γ_{1k} is the random intercept at level 3, $\gamma_{2j(k)}$ the random intercept at level 2, and ε_{ijk} the random error at level 1. All independent variables were centered at their means to simplify interpretation. We implemented all models in SAS® version 9.1 (SAS Institute, Inc., Cary, NC) using Proc Mixed and the restricted maximum likelihood method. Model results were used to adjust estimates of mean blood pressure and hypertension prevalence for bias in measurement of blood pressure under the assumption that measurement errors are normally distributed conditional on the true, error-free, but unknown blood pressure (eAppendix, http://links.lww.com).

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Reliability study in Add Health

In a separate quality-control study conducted over the course of field work, short-term reliability of blood pressure was assessed among a race/ethnicity- and sex-stratified random sample of 100 Add Health, Wave IV participants (mean age 29 yr; 50% female; 64% non-Hispanic white, 16% non-Hispanic black, 12% Hispanic/Latino, 8% other). The participants were examined twice, one to two weeks (mean: 8.5 days) apart. At each of the two examinations, systolic and diastolic BPs were measured following the protocol described above, typically by the same field interviewer (84% of participants) and at approximately the same time of day (mean absolute difference: 52 minutes; range 0–302 minutes).

A nested, random-effects model was first used to partition the variance of systolic BP (and separately, diastolic BP) into its components:

$$Y_{ijkl}=\mu+F_i+P_j(F_i)+V_k(F_i,P_j)+M_l(F_i,P_j,V_k)+\varepsilon_{ijkl},$$

where Y is the blood pressure recorded by the ith FI (F_i) on the jth participant (P_j) within the kth visit (V_k) at the lth measure (M_l), μ is the intercept, and ε_{ijkl} is the error. Based on this model, the terms of which are assumed to be independent, the total variance (σ_T^2) is:

$$Var(Y_{ijkl})=\sigma_{BF}^2+\sigma_{BP}^2+\sigma_{BV}^2+\sigma_{BM}^2+\sigma_{WM}^2,$$

where $_{BF}$, $_{BP}$, $_{BV}$, $_{BM}$, and $_{WM}$ indicate the between-field-interviewer, between-participant, between-visit, between-measure, and within-measure variances, the latter from the error term defined above. Because blood pressure measurement was automated and typically performed at both visits by the same field-interviewer, a simpler model was adopted, $Y_{ijk} = \mu + P_i+V_j(P_i)+\varepsilon_{ijk}$, for which $\sigma_T^2=\sigma_{BP}^2+\sigma_{BV}^2+\sigma_{WV}^2$. This simplification was consistent with observations that between-field-interviewer variances made negligible contributions to σ_T^2 (4% for systolic BP and 3% for diastolic BP). To facilitate comparison with exam center-based studies of cardiovascular disease, reliability was then computed as the ratio of the between-participant variance to total variance (σ_{BP}^2/σ_T^2), i.e. an intra-class correlation coefficient with 95% confidence intervals (CIs) computed using the delta method under the assumption of normality.[22] The intra-class correlation coefficient represents the proportion of variance in blood pressure that is not due to measurement variance, and can be interpreted as the correlation between repeated measurements on the same individual. All models were implemented in SAS® 9.1 using Proc Mixed and the restricted maximum likelihood method.

RESULTS

Cross-survey comparisons

Compared with NHANES, participants in Add Health were less likely to be foreign-born, uninsured, and have less than a high school education, and more likely to be obese (37% versus 28%, Table 1).

The prevalence of hypertension (defined as systolic BP/diastolic BP ≥ 140/90 mm Hg) was much higher in the Add Health, Wave IV population (19% [95% CI = 18%–20%]) compared with persons of the same age in the NHANES population (4% [2%–6%]). Nonetheless, self-reported history of hypertension among young adults was similar in Add Health (11% [95% CI = 10%–12%]) and NHANES (9% [7%–12%]) (Figure 1). Hence, approximately twice as many young adults in NHANES had self-reported versus measured hypertension, the reverse of the pattern found in Add Health. Among those with self-reported hypertension, approximately one-fifth of NHANES (versus one-half of Add Health) participants had elevated blood pressure by study measurement (data not shown).

Potential sources of difference

Consistent differences between populations in mean systolic and diastolic BP (usually ≥ 10 mm Hg) and hypertension prevalence (usually ≥ 15%) were found in all sociodemographic subgroups, although the differences were smallest among normal-weight and underweight participants (Table 2). Survey weights and propensity for differential selection into Add Health versus NHANES (eTable 1; http://links.lww.com) failed to account for the between-study differences in mean blood pressure or hypertension prevalence (Table 3). The adjusted odds of hypertension in Add Health versus NHANES was 6.6 (95% CI = 4.0–11.0). Further adjustment for anti-hypertensive medication use had relatively little effect on the odds ratio, but reduced its precision due to small cell sizes.

Measurement Context and Interview Content

Among NHANES III (1988–1994) participants aged 24–32 years who were examined twice, mean in-home and mobile-examination-center measures of systolic and diastolic BP were similar: 115 (95% CI = 114–116) and 72 (71–72) mm Hg versus 112 (111–113) and 71 (70–72) mm Hg, respectively. Among the 100 Add Health, Wave IV participants examined twice, mean systolic and diastolic BP after the 1.5-hour interview (Visit 1) and 5-minute interview (Visit 2) were also similar: 124 standard deviation (12) and 79 (10) versus 123 (13) and 77 (10) mm Hg, respectively.

Digit preference

Overall, there was little evidence of systematic blood pressure digit preference (eTable 2; http://links.lww.com). Although each diastolic BP measure was associated with a significant overall χ^2 test (Bonferroni-corrected $P < 8 \times 10^{-3}$), all corresponding digit-preference-score values were < 20. Two (0.6%) of 323 field interviewers exhibited digit preference in one of six blood pressure measures (Bonferroni corrected $P < 2 \times 10^{-5}$; digit preference score > 20). Blood pressures from both of these field interviewers were excluded from all reported hypertension estimates (n = 227), although only one of them exhibited digit preference ($P <$ 0.00001 for all six measures; digit preference score range, 33.8–42.0). When we reviewed this field interviewer’s validity study data, we did not find equipment damage, missing parts, electronic malfunction, or atypical bias (range: −3.8 to 2.8 mm Hg). However, data collected by this field interviewer from 111 (< 1%) of the 14,800 participants with valid survey weights included an extreme excess of systolic and diastolic BP values equal to 120 and 70 mm Hg, respectively.

Bias and relative bias

Bias in pressure measurement was approximately normal in its distribution, with a mean at 0 mm Hg (eFigure 1, http://links.lww.com). Bland-Altman 95% limits of agreement between the monitored and metered pressures were −13 and + 13 mm Hg. Although mean bias and relative bias approximated 0 at 140 and 160 mm Hg—well-known Joint National Committee 7 thresholds for the diagnosis of hypertension—they steadily increased at higher and lower pressures (eTable 3, http://link.lww.com). However, at the tested extremes (280 mm Hg and 40 mm Hg), mean bias remained less than 2 mm Hg and corresponding measures of relative bias never exceeded 4%. Moreover, absolute bias (i.e. the difference between monitor and meter pressures irrespective of its direction) did not exceed 2.2 mm Hg across the measured range of pressure.

Predictors of bias

Meter pressure was by far the strongest predictor of bias. As pressure increased from 40 mm Hg, bias steadily decreased, becoming significantly negative at approximately 150 mm Hg. The only other important predictor of bias was number of missing pressures. Each additional missing value was associated with a −0.15 mm Hg (standard error = 0.02) decrease in mean bias. A graph of the predicted mean bias versus meter pressure revealed inflection points at approximately 100 and 200 mm Hg, below and above which the slope of the bias-pressure association was relatively low compared with that at intermediate pressures (Figure 2).

Reliability

Intra-class correlation coefficients and 95% CIs for the first, second, third, first through third, and mean of the second and third blood pressure measures were 0.65, 0.75, 0.66, 0.67 and 0.81, for systolic BP and 0.59, 0.60, 0.69, 0.63 and 0.68 for diastolic BP, respectively (eTable 4, http://links.lww.com). Accounting for the interval between visits (days) and difference in time of day (minutes) produced negligible changes in these estimates (data not shown).

Blood pressure and hypertension in Add Health and NHANES

In Add Health, the overall weighted mean systolic BP (range 74–223 mm Hg) and diastolic BP (range 30–147 mm Hg) fell in the pre-hypertensive and high normotensive categories. In Add Health, only 3% (95% CI = 3%–4%) had hypertension based solely on use of anti-hypertensive medication (Table 4). The prevalence of hypertension, however, increased four-fold when the definition of this disease was expanded by including history of being told by a health care professional that a participant had hypertension. The prevalence doubled yet again when the definition was broadened by incorporating stage 1 or 2 hypertension. These findings were similar to those found before excluding the two field interviewers exhibiting digit preference. Bias adjustment (Table 4) and exclusion of participants with undersized cuffs (i.e. arm circumference exceeded large adult cuff; n = 201) had small effects on estimates. A lack of concordance between the field interviewers and the participant on sex and race/ethnicity had negligible association with blood pressure (eTable 5, http://links.lww.com).

The prevalence of hypertension defined by medication use or self-reported history of hypertension was similar between Add Health (12%) and NHANES (10%). However, hypertension defined by medication use, history of hypertension or systolic BP/diastolic BP ≥140/90 mm Hg was twice as high in Add Health (26%) as in NHANES (12%) (Table 4).

DISCUSSION

Several national field studies have produced population-wide inferences regarding the prevalence of hypertension for older cohorts in the United States.[23,24] However, few studies have described procedures for assuring and controlling quality of in-home blood pressure data collected by a large, centrally managed, national field staff using portable and affordable blood pressure monitors. The present report describes the methods used by Add Health, Wave IV (2008) to estimate the validity and reliability of blood pressure (digit preference; bias; intra-class correlation), and bias-adjusted prevalence of hypertension based on blood pressure data collected using the aforementioned methods.

The resulting estimates suggest that in Add Health, terminal digit preference of blood pressure is infrequent, bias is low, short-term reliability is good to excellent, and comparable to that found in well-known, exam center-based studies of cardiovascular disease.[10,25,26] The estimates also suggest that, although the measured prevalence of hypertension (i.e. BP ≥

140/90 mm Hg) is four- to-five-fold higher in Add Health, Wave IV (2008) than in NHANES (2007–2008) among participants aged 24–32, self-reported history of hypertension is similar in the two populations. Hence, the proportion of young adults in NHANES reporting a history of hypertension is twice that with measured hypertension (9% versus 4%), while the reverse holds in Add Health (11% versus 19%, see Figure 1). The Add Health findings are consistent with the expectation that blood pressure measurement will capture subclinical hypertension (i.e. hypertension unknown to otherwise healthy young people), and in doing so, will identify more measured than self-reported cases.

The striking between-survey difference exists despite examination of young adults in the same age range (24–32 years) during an overlapping time frame and despite Add Health's efforts to examine and account for numerous methodologic concerns. These concerns included the following: digit preference; validity; reliability; survey weights; differential selection; use of anti-hypertensive medications (important given a recent report documenting improvements in hypertension treatment and control[27]); consumption of food, caffeinated beverages, or smoking prior to blood pressure measurement; time of blood pressure measurement; measurement context; and interview content. Important between-survey differences in sampling frame and study design determine the distinct populations to which Add Health and NHANES findings are most appropriately inferred. These differences may help explain the observed discordance in hypertension prevalence between studies, without labeling either as incorrect. In Add Health, the appropriate inference is to persons who were adolescents in grades 7–12 in the U.S. during the 1994–95 school year, including those who subsequently joined the military or were institutionalized or incarcerated. In NHANES, the appropriate inference is to the U.S. civilian, non-institutionalized population during 2007–2008, one similar to that described by the U.S. Census Bureau's American Community Survey (2008),[28] yet less likely than Add Health to include non-Hispanic white, native-born, better-educated, and health-insured persons (eTable 6, http://links.lww.com). Furthermore, Add Health includes participants who were waiting to have blood pressure measurements taken by a field interviewer in the participant's homes, whereas NHANES participants had to go to a mobile examination center for blood pressure measurement by physician examiners.

Although the differences in sampling frame and study design increase the possibility of divergent biases, directly standardizing rates of BP ≥ 140/90 mm Hg in Add Health Wave IV to the U.S. population aged 24–32 years based on race/ethnicity, foreign birth or education in the American Community Survey 2008 or NHANES 2007–2008 produced estimates (range: 18.6%, 19.6 %) that differed little from the overall unadjusted prevalence (18.6%–19.6% versus 19.1%; eTable 6; http://links.lww.com). Subgroup-specific rates and mean blood pressure were both higher in Add Health than in NHANES, even among those typically at lower risk of hypertension, e.g. the health-insured, better-educated and non-Hispanic whites. Propensity-scored estimates adjusting simultaneously for an array of salient study participant characteristics also diverged little from the unadjusted estimates. Furthermore, the adjusted odds of measured hypertension in Add Health was more than six times that in NHANES.

Robustness aside, estimated rates of hypertension approaching nearly one in five U.S. young adults raise questions about their biological plausibility. However, there is global precedent for such observations; for instance, among Latin American and Caribbean men aged 20–29, the rate of hypertension (defined as systolic/diastolic BP ≥ 140/90 or taking anti-hypertensive medications) is 28%.[29] Though such high rates have not been described previously in the U.S., prior findings in the global context suggest that they are neither biologically implausible nor without epidemiologic precedent.

The large and unexplained differences between Add Health and NHANES merit further investigation. U.S. coronary heart disease mortality and policy models rely heavily on NHANES systolic BP distributions and, in some cases, on optimistic assumptions regarding relatively small decreases of 0–1 mm Hg per year in population mean systolic BP.[30,31] Although consideration may well focus on between-study differences in measurement methods[32,33] and observer bias, neither appears to be problematic insofar as NHANES blood pressure measurement is concerned.[11,34] Indeed, sphygmomanometric and automated oscillometric blood pressure measures are much more similar among adult than pediatric populations.[32,33,35]

Study strengths and limitations

In a nationally representative field study, we investigated two important problems that can threaten the integrity of blood pressure measurements: lack of validity and reliability. This investigation is subject to several limitations. Under ideal circumstances, validity of blood pressure measurements would have been monitored on an ongoing basis throughout Wave IV of the Add Health study. Given the decentralized nature and geographic breadth of data collection, doing so was not practical. It also would have been useful to examine additional factors capable of affecting reliability of blood pressure, such as fasting status of participants or demographic mismatching of participants and field interviewers. However, the contribution of these factors to the reliability of blood pressure measurement was expected to be relatively small[19] compared with the high cost of studying large enough sample sizes to provide adequate power for the examination of subgroup differences in reliability.

Finally, the proportion of Add-Health, Wave-IV participants defined as having hypertension on the basis of elevated blood pressure alone may have been affected by blood pressure measurement variation.[36] The potential importance of this possibility is underscored by the similarity of the blood pressure monitor used in this study to a different monitor made by the same manufacturer, and its association with a standard deviation slightly higher than that of several other monitors examined in the literature.[37,38] However, Add Health’s blood pressure monitor was manufactured to meet U.S. and European standards. The British Hypertension Society validated the monitor, assigned it an A/A grading, and gave it their highest recommendation “for clinical and home use.”[39,40] Its precision, validity and reliability are documented here. In addition, the putative effect of measurement variability was attenuated in this context by obtaining and averaging multiple blood pressure readings, and by using an automatic oscillometric device, which has been associated with a decrease in terminal digit preference.[41] Together, these findings suggest that measurement variation is unlikely to account for the observed magnitude of difference between populations. A small percentage of participants may have been taking anti-hypertensive medications for other indications. Medication history and inventory are nonetheless routinely used in health surveys like NHANES[42] to help define hypertension.

Conclusions

Carefully standardized, in-home measurement using an inexpensive oscillometric monitor can produce valid and reliable estimates of blood pressure. Coupling Joint National Committee 7 classification[14] of Add Health’s valid, reliable and publicly available blood pressure data with the study’s self-reported history of hypertension and inventory of anti-hypertensive medications allows researchers to study the epidemiology of hypertension in a nationally representative sample of young adults. The prevalence of hypertension among Add-Health Wave-IV participants indicates an unexpectedly high risk of cardiovascular disease among U.S. young adults and deserves further scrutiny.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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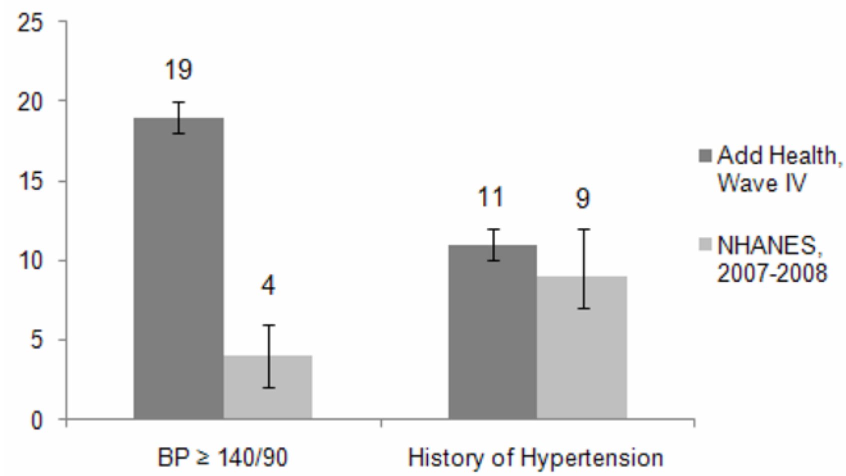

Figure 1.
Exam-based and Self-reported Measures of Hypertension

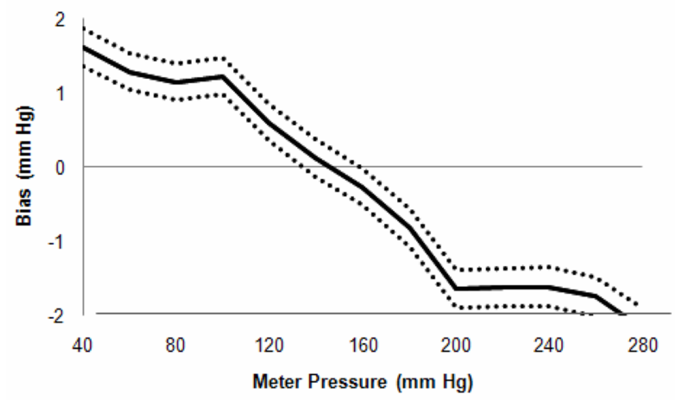

Figure 2.
Predicted Mean Bias Versus Metered Pressure

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Table 1

Participant Characteristics, Ages 24–32 Years[a]

	Add Health Wave IV (2008)		NHANES (2007–2008)	
	No.	**Mean or %[b] (95% CI)**	**No.**	**Mean or %[c] (95% CI)**
Age (years); mean	14,252	28(28–29)	733	28(28–28)
Men; %	6683	51(49–52)	363	51(46–56)
Race/ethnicity; %				
White, non-Hispanic	7636	66(60–72)	287	62(50–73)
Black, non-Hispanic	2837	15(11–19)	160	13(9–18)
Asian/Pacific Islander, non-Hispanic	813	3(2–5)		
Mexican	958	6(4–9)	173	13(9–19)
Cuban	266	1(0–2)		
Puerto Rican	334	1(1–2)		
Other Hispanic	464	3(2–4)	85	6(4–10)
Other/multiracial	883	5(4–6)	28	6(3–11)
Foreign-born; %	870	4(3–6)	185	19(13–26)
Education[d]; %				
< High School	1100	9(8–11)	194	19(15–24)
High school/GED	2279	18(16–20)	178	22(18–27)
Some college/ AA	6298	43(41–45)	212	31(26–37)
4-Year college	4572	30(27–33)	149	28(21–35)
Household income ≤ $20,000; %	1527	12(11–14)	143	15(11–20)
Uninsured; %	2927	22(21–24)	285	31(25–37)
Current daily smoker; %	3054	25(23–27)	171	23(17–31)
Heavy drinking[e] in past 12 months; %				
None	7508	50(48–52)	398	53(49–57)
< Weekly	5104	38(36–40)	198	33(29–36)
≥ Weekly	1587	12(11–13)	92	14(13–16)
BMI; %				
Underweight	197	1(1–2)	11	1(1–3)

	Add Health Wave IV (2008)		NHANES (2007–2008)	
	No.	Mean or %[b] (95% CI)	No.	Mean or %[c] (95% CI)
Normal weight	4363	32(31–34)	254	40(36–44)
Overweight	4124	30(29–31)	219	30(27–33)
Obese class I	2501	19(18–20)	106	14(12–17)
Obese class II/III	2444	18(16–19)	115	14(10–19)
No food, coffee, cigarettes in past 30 min; %	10,094	70(68–71)	551	74(71–78)
Measurement session; %				
Morning	6390	45(43–47)	342	47(41–53)
Afternoon	4461	32(31–33)	254	34(27–42)
Evening	3340	23(22–24)	137	19(14–24)
Anti-hypertensive medication use[f]; %	465	3(3–4)	18	2(1–3)

[a] Participants with valid blood pressure data.

[b] Percents (95% confidence interval) weighted to be representative of adolescents in grades 7–12 in the U.S. during the1994–1995 school year.

[c] Weighted percents (95% CI).

[d] GED = General Educational Development or high school equivalency degree; AA = Associate’s Degree.

[e] Add Health men: ≥ 5 drinks in a row (women ≥ 4); NHANES: ≥ 5 drinks in a day.

[f] Use of a beta-blocker, calcium channel blocker, angiotensin converting enzyme inhibitor, angiotensin II. receptor blocker, anti-adrenergic, vasodilator, thiazide diuretic or antihypertensive combinations

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Table 2

Mean Blood Pressure (BP) and Hypertension by Participant Characteristics, Ages 24–32 Years

	Add Health, Wave IV (2008)				NHANES (2007–2008)			
				BP ≥ 140/90				BP ≥ 140/90
	No.	**Systolic BP[a](SD)**	**Diastolic BP[a](SD)**	**%[a](95% CI)**	**No.**	**Systolic BP[b](SD)**	**Diastolic BP[b](SD)**	**%[b](95% CI)**
All	14,252	125(14)	79(10)	19(18–20)	733	114(9)	67(9)	4(2–6)
Sex								
Men	6683	130(12)	82(10)	27(25–28)	363	118(8)	68(9)	5(3–9)
Women	7569	120(13)	77(10)	11(10–12)	370	110(9)	66(10)	3(1–5)[c]
Race/ethnicity								
White, non-Hispanic	7636	125(12)	79(9)	18(17–20)	287	114(7)	68(7)	4(2–6)
Black, non-Hispanic	2837	126(17)	80(13)	21(19–23)	160	115(13)	67(14)	5(3–10)
Asian/Pacific Islander, non-Hispanic	813	124(21)	80(15)	21(17–26)				
Mexican	958	125(14)	80(11)	21(17–25)	173	114(12)	67(14)	4(2–9)[c]
Cuban	266	124(31)	79(19)	19(9–35)				
Puerto Rican	334	124(18)	78(13)	15(8–26)				
Other Hispanic	464	123(13)	78(10)	13(10–18)	85	114(13)	65(14)	2(0–10)[c]
Other/multiracial	883	125(16)	80(11)	22(18–27)	28	111(5)	68(6)	
Immigrant Status								
US born	13,382	125(13)	79(10)	19(18–20)	548	114(9)	67(9)	4(3–7)
Foreign-born	870	123(16)	78(12)	16(13–20)	185	113(10)	66(10)	2(1–5)[c]
Education[d]								
< High School	1100	126(13)	80(9)	22(19–25)	194	115(10)	67(11)	3(2–7)[c]
High school/GED	2279	127(13)	80(10)	22(20–25)	178	115(11)	66(10)	4(2–10)[c]
Some college/ AA	6298	125(14)	80(10)	19(18–20)	212	113(9)	68(9)	4(3–7)
4-Year college	4572	123(13)	78(10)	17(15–18)	149	113(7)	67(7)	3(1–10)[c]
Household income								
≤ $20,000	1527	126(14)	80(10)	21(18–24)	143	114(9)	67(10)	2(1–7)[c]

	Add Health, Wave IV (2008)				NHANES (2007–2008)			
				BP ≥ 140/90				BP ≥ 140/90
	No.	Systolic BP[a](SD)	Diastolic BP[a](SD)	%[a](95% CI)	No.	Systolic BP[b](SD)	Diastolic BP[b](SD)	%[b](95% CI)
> $20,000	11,797	125(13)	79(10)	19(18–20)	560	114(9)	67(9)	4(2–6)
Insurance status								
Insured	11,305	125(13)	79(10)	18(17–19)	448	113(9)	67(9)	4(2–6)
Uninsured	2927	126(14)	80(10)	22(20–25)	285	115(10)	67(10)	4(1–10)[c]
Daily smoking								
Yes	3054	126(13)	80(10)	22(20–24)	171	116(9)	67(10)	2(1–10)[c]
No	11,083	125(14)	79(10)	18(17–19)	562	113(9)	67(9)	4(2–7)
Heavy drinking								
None	7508	124(14)	79(10)	18(17–19)	398	112(9)	67(9)	3(1–5)
< Weekly	5104	125(13)	79(10)	18(17–20)	198	114(8)	66(9)	5(3–8)
≥ Weekly	1587	129(13)	82(10)	26(23–29)	92	119(8)	69(10)	5(2–15)[c]
BMI								
Underweight	197	113(13)	74(10)	6(3–12)	11	108(10)	70(7)	6(1–27)[c]
Normal weight	4363	120(12)	76(9)	11(9–12)	254	112(8)	67(7)	2(1–4)
Overweight	4124	126(12)	80(10)	19(18–21)	219	114(9)	67(10)	4(2–10)[c]
Obese class I	2501	129(13)	82(10)	25(23–28)	106	116(10)	68(10)	6(2–17)[c]
Obese class II/III	2444	131(14)	83(10)	31(29–34)	115	117(10)	69(10)	4(2–10)[c]
No food/drink/smoking[e]	10,094	125(14)	79(10)	19(18–20)	551	113(9)	68(9)	4(2–6)
Measurement session								
Morning	6390	124(14)	79(10)	18(17–19)	342	113(8)	67(9)	2(1–3)
Afternoon	4461	125(13)	79(10)	18(17–20)	254	114(10)	67(10)	4(2–9)[c]
Evening	3340	127(14)	80(10)	23(21–25)	137	115(9)	69(9)	7(3–16)[c]
Medication use[f]								
Yes	465	132(16)	85(12)	40(34–46)	18	121(16)	74(11)	11(3–36)[c]
No	13,787	125(13)	79(10)	18(17–19)	715	114(9)	67(9)	4(2–6)[c]

[a]Means (standard deviations), percents (95% CI) weighted to be representative of adolescents in grades 7–12 in the U.S. during the1994–95 school year.

[b] Weighted means (standard deviations), percents (95% CI).

[c] Estimate should be interpreted with caution: relative standard error > 30% (National Center for Health Statistics, Centers for Disease Control and Prevention. Analytic and Reporting Guidelines: The National Health and Nutrition Examination Survey (NHANES). Hyattsville, Maryland, 2006).

[d] GED = General Educational Development or high school equivalency degree; AA = Associate's Degree.

[e] No food, caffeine or smoking in past 30 minutes.

[f] Use of a beta-blocker, calcium channel blocker, angiotensin converting enzyme inhibitor, angiotensin II receptor blocker, anti-adrenergic, vasodilator, thiazide diuretic or antihypertensive combinations.

Table 3

Effect of Weighting and Propensity Scoring on Mean Blood Pressure (BP) and Hypertension Prevalence, Ages 24–32 Years

	Add Health, Wave IV (2008)				NHANES (2007–2008)				Odds of hypertension in Add Health vs. NHANES	
									n = 13,058	
				BP ≥ 140/90				BP ≥ 140/90	Crude	Adjusted
	No.	Systolic BP	Diastolic BP	%(95% CI)	No.	Systolic BP	Diastolic BP	%(95% CI)	OR(95% CI)	OR[b] (95% CI)
Unweighted	12,422	125	79	19	636	114	67	3	6.5(4.2–9.9)	6.6(4.2, 10.2)
Weighted	12,422	125	80	20(19–21)	636	114	67	4(2–6)	6.2(3.8–10.0)	5.2(3.2–8.7)
Propensity-scored[a]	12,422	125	79	18(17–20)	636	114	66	3(1–5)	8.6(4.7–16.0)	6.6(4.0–11.0)

[a] Adjusted for the predicted probability of being in the Add Health (versus NHANES) population conditional on age, gender, race/ethnicity, foreign-birth, education, income, health insurance, smoking, alcohol use, BMI status, consumption of food, coffee or smoking 30 minutes prior to BP measurement (separate items), and measurement session.

[b] Logistic regression model included all above-listed covariates.

Table 4

Mean Blood Pressure (BP) and Hypertension Prevalence and the Effect of Bias Adjustment on Add Health Estimates, Ages 24–32 Years

	Add Health, Wave IV (2008)			NHANES (2007–2008)	
			Bias-adjusted[c]		
Measure	No.[a]	Mean or %[b] (95% CI)	Mean or %[b] (95% CI)	No.[a]	Mean or %[d] (95% CI)
Systolic BP (mm Hg); mean	14252	125(125–125)	124(124–125)	733	114(113–115)
Diastolic BP (mm Hg); mean	14252	79(79–80)	78(78–79)	733	67(66–68)
Systolic BP ≥ 140 or diastolic BP ≥ 90 mm Hg; %	2643	19(18–20)	17(16–18)	26	4(2–6)
Medication use[e]; %	481	3(3–4)		19	2(1–4)
History of hypertension;%	1532	11(10–12)		75	9(7–12)
Medication use[e] or history; %	1630	12(11–13)		79	10(8–12)
Medication use,[e] history, systolic BP ≥ 160 or diastolic BP ≥ 100[f]; %	1912	14(13–15)	14(13–15)	80	10(8–13)
Medication use,[e] history, systolic BP ≥ 140 or diastolic BP ≥ 90[f]; %	3579	26(25–27)	25(23–26)	93	12(9–15)
Medication use,[e] history, systolic BP ≥ 120 or diastolic BP ≥ 80[f]; %	9669	69(68–70)	65(64–67)	268	36(32–41)

[a] Unweighted sample size.

[b] Percents (95% confidence interval) weighted to be representative of adolescents in grades 7–12 in the U.S. during the1994–95 school year.

[c] Adjusted for measurement error (see eAppendix).

[d] Weighted percents (95% confidence interval).

[e] Use of a beta-blocker, calcium channel blocker, angiotensin converting enzyme inhibitor, angiotensin II receptor blocker, anti-adrenergic, vasodilator, thiazide diuretic or antihypertensive combinations.

[f] Joint National Committee 7 Stage 2 (160/100 mm Hg), Stage 1 (140/90 mm Hg), and pre-hypertension (120/80 mm Hg).